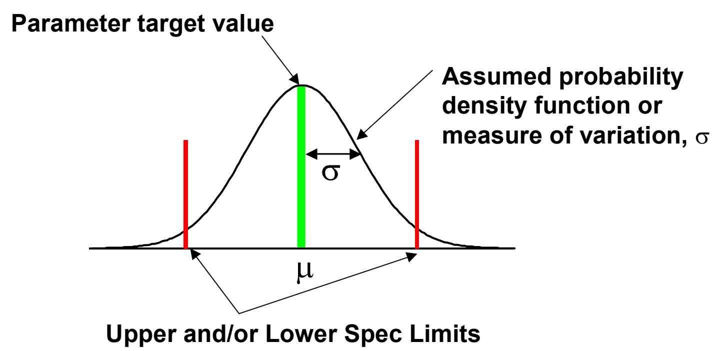
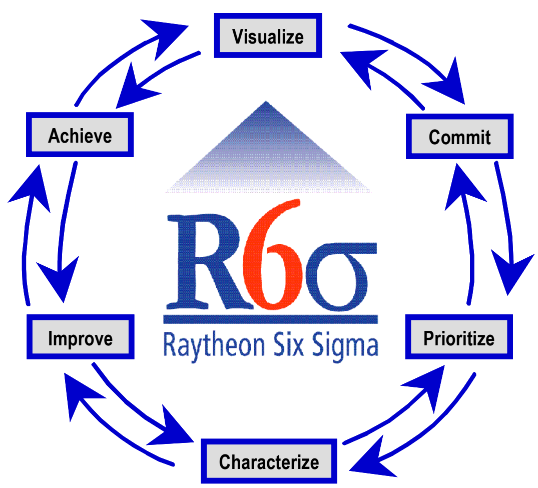
Raytheon Six Sigma / Design for Six Sigma
the Road Map to Success

INTRODUCTION:



Classical Six Sigma (6σ) is focused on making and/or improving all manufacturing, and assembly processes such that every process has a 6σ process capability or a Cpk of 2.0. Every Process has a mean, a standard or non-standard distribution, and an upper and lower specification limits. The "Goal" of 6σ is to improve the process capability of all processes, regardless and without consideration to the net gain or business impact. Not all process improvements will net a positive cost impact to the Business's bottom line. The emphasis on Design for Six Sigma came about because the design dictates the manufacturing tolerances, processes, sub-assembly processes, and system level assembly processes. Once a product or system is designed, there is minimal amount of impact the operations side of the business can have to reduce the cost of the product. Over specification of tolerances or tight tolerances, are usually driven because of lack of knowledge of functional design requirements, or because the engineer did not have the time or take the time to complete a tolerance analysis. This over specification of tolerances drives manufacturing cost, increases defects, and does not guarantee functionality.



Raytheon Six Sigma (**R6σ**) involves the same statistical requirements as implemented in 6σ, while adding lean manufacturing concepts, and process improvements (not just manufacturing process but for any process), and ties the decision making to the bottom line cost impact. The financial bottom line drives the "What", and "When" to determine "If" a process improvement is needed. The intention of this paper is not to discuss a successful implementation of Design for Manufacture and Assembly (DFMA) and/or Design for Six Sigma (DfSS) into the development of a product. The intention is to show the process you can use to successfully implement the use of both DfSS and DFMA to improve the design of a product. **R6σ** involves a six-step process, which in and by itself is a rather simple process. However, the purpose for following the six steps of the process is to assure that the Integrated Product Team (IPT) members step through the process, and to assure that the IPT members do not jump from the **PROBLEM** to the assumed best **SOLUTON** without understanding all of ramifications of their design approach: performance, first time build, rework cost ramifications, etc. When working a **R6σ** project we insist that the IPT members involved in the project understand the **R6σ** process and follow it.

CASE FOR ACTION:

Performance is just a part of the picture. However, in the defense industry, it historically is the Engineer's primary focus. When designing systems for the military, it is imperative to look at the bigger picture. We cannot afford to just focus on performance. YES, performance of the system is important, but we also need to establish “Design to Cost” goals for every part, sub-assembly, and for the system level assembly, and we need to work to meet the goals. If the IPT does not focus on the cost objectives of the program, they may end up designing the Customer a Jaguar, when all he wanted and could afford was a Mini-Cooper! We also need to look at the recurring cost of manufacturing, assembling, testing, and sustaining the system. Our customer supports the idea of trying to control the cost of the defense systems. Our Military Customer uses a process known as Cost As an Independent Variable (CAIV), where they ask their suppliers to work with them in trying to reduce the cost of their systems by trading performance requirement parameters for a reduction in cost. Design for Six Sigma, Design for Assembly, Design for Manufacture, Tolerance Analysis, Statistical Tolerance Allocation, Defect Drivers & Yields, each is just a part of the picture, and it is imperative that we look at the bigger picture!

Companies that design and manufacture products for Military customers face a somewhat unusual challenge compared to that of their counterparts in commercial industries. Not only do the companies within the defense industry need to get their products into the market quickly (meet their schedules), but they must also produce designs that meet their functional system requirement, and they must meet the design to cost budget. However, if the products don't meet the functional requirements of the systems, 100% of the time, it could possibly mean the loss of a serviceman’s life and the lives of the other servicemen with him/her. We are faced with the fact that our products are used in a harsh environment. It is an IMMINENT LIFE AND DEATH ENVIRONMENT. That is the challenge facing engineers at Raytheon Company. We are tasked with the reality of trying to design something that functions 100% of the time. Lives depend on it.

We are trying to protect our armed forces. Whatever we put into the field for the soldier to use, we strive to assure that it meets the systems functional requirements, and I am positive the Soldier or the Marine relying on it to perform wants the same. We also are faced with the reality, that fellow employees who are in the military reserve and in some cases even our sons, daughters, brothers, and sisters are the soldiers who will be using our systems! On the flip side, the Military Program Offices are tightening their budgets, they are faced with some tough decisions. They have to supply the best system for the least dollars, and they realize that a big portion of the budget funding goes to supporting the soldiers in the field.

THE SIX STEPS FOR DESIGN FOR SIX SIGMA (DFSS):

Step 1: VISUALIZE

Visualize is the first step in the process. If we discuss the “Goals” of any design, we have to understand that the “Goals” involve more than just the performance of the system.

Visualize - Develop a Common Vision:

- ✓ What does the Customer want?
- ✓ What does the Company want?
- ✓ As an Engineer, what do I want?

What does the Customer, and the end user TRULY WANT? The Customer has three basic concerns: cost, quality and schedule, and it appears that in today’s environment they all have an equal importance. However, if we look at the real Customer – the end user, his goal is that the system performs flawlessly every time. However, if we develop a system the Customer cannot afford, or is not within their “Price Target”, they will walk away from the program. Just like you or I would walk away from the Jaguar if all we could afford is a Mini Cooper! It is imperative that we develop and design a product which not only meet the Customer’s performance requirements, but must also meet their cost goals.

Customer’s Product Goals:

- ✓ System physical size requirements
- ✓ System physical weight
- ✓ Mission or operation life
- ✓ Operating temperatures
- ✓ Vibration
- ✓ Mechanical shock

- ✓ System Level Cost Goals
- ✓ Mean Time Between Failure (MTBF)
- ✓ Life Cycle Cost
- ✓ Depot Repair Cost
- ✓ Etc.

System design engineers are tasked with meeting the entire range of system level design performance requirements and diligently work to meet the technical issues. However, for some reason, they rarely focus on meeting the cost goals. On the other hand, the Company and Program Management (PM's) are not only faced with meeting the entire range of system level design performance requirements (or goals), but they are also faced with profit goals, design support costs, and schedule dates:

Program Management's Goals:

- ✓ Meeting all of the design requirements & specifications
- ✓ Meeting the program schedule
- ✓ Meeting the cost performance budget
- ✓ Meeting material cost goals
- ✓ Etc.

If you were a member of the IPT, and as a member of the IPT you were tasked with designing a Laptop Computer. One of the first things you would do was to start developing a systems performance specification.

Laptop Computer Performance Specification:

- ✓ Processor Speed
- ✓ Amount of random access memory (RAM)
- ✓ System weight
- ✓ Hours of continuous operation with battery power.
- ✓ Compact Disk – DVD/RW
- ✓ Etc

However, as an IPT member you should also recognize the fact that to make the program successful, you need to also establish some business related goals, such as:

Laptop Computer Business Related Goals:

- ✓ System Design to Cost Goals
- ✓ Hours per unit assembly
- ✓ Hours per unit test
- ✓ Final acceptance test yield
- ✓ Rework hours per unit
- ✓ Rework Cost
- ✓ Etc.

Engineers need to understand that no matter what type of business, whether it's commercial, industrial, automotive, or defense, you will be tasked with developing a design that not only meets the performance and business related requirements, but must also be one that can be manufactured and assembled within cost targets, and within the Customer's Price Target! Early in the conceptual and detailed design phase of the program, we must learn to look at the cost of manufacturing, processing, painting, plating, coating, assembly, and testing. If the overall system costs are out of line, we will be unable to sell the product for a sufficient profit margin, killing the program!

Step 2: <u>COMMIT</u>

IPT must Commit to working for and with the Customer and to having a Customer Focus!

Work together as a Team: Program Management, Design, Manufacturing, Assembly AND the Customer!

The IPT members, must commit to doing what is best for the Customer, the Company, and the Employee! Work with the Customer, Program Management and Integrated Product Development Team to develop a Common Vision and Commitment. Commit is undoubtedly the most difficult of all the steps. The IPT members need to be committed to designing a system that meets not only technical performance, but also on system cost, and schedule goals.

Step 3: <u>PRIORITIZE</u>
What are the Top 10 Material Cost Drivers, for the proposed design? (Parts, Materials, Labor, Purchased Parts, Assembly, Test, etc.)

What are the system's Top 10 Defect Drivers for the proposed design?

Next is **<u>PRIORITIZE</u>**. The IPT needs to develop a method to focus and/or prioritize their work. Some say the first steps should be to evaluate the system performance requirements, and then knowing the performance requirements the IPT should assign processes that have a six-sigma process capability, and meet all of the performance specifications. However, since Raytheon and many other Companies have transitioned to top-level assembly integration businesses which do not manufacture the majority of the parts and sub-assemblies that go into their products, frequently there is little the engineer can do to improve the process capability of a particular part or sub-assembly because either the parts and/or sub-assemblies is a commodity part, or the supplier is unable or unwilling to invest in process improvements. The first step of every new design or redesign should be to evaluate the system at the system level to better understand the system performance, system yields, first time build cost and hours per unit (HPU), sub-assembly cost and HPU, rework cost and HPU, and test cost and HPU, and the cost and HPU's rework the failures. Once the team understands the system level performance, yields, HPU and costs, then the IPT should focus on what is causing the largest cost problem. The IPT needs to pareto the performance, yields, HPU, and/or costs to determine what they will attack first. The part or sub-assembly that has the poorest yield, or the lowest Process Capability is not necessarily the issue that should be addressed by the IPT. The IPT needs to focus on the part or sub-assembly that has the most significant impact relative to the business obligations. Prioritization of the Assembly HPU, Test HPU, Material Cost Drivers, and the potential System Defect Drivers is a good place to start.

If you as an engineer, have never designed the system before, how can you prioritize the cost drives, and the yield drivers? This is intended to be a high level Prioritization. Rarely if ever, do we design a system from scratch. We take an existing design and morph it into our new application.

As an engineer on the IPT, if you were asked to design a new laptop computer, and you wanted to determine the top system level cost drivers. You and the other IPT members could "Brainstorm" the list. Once you have the list, you could then use a tool like BDI's DFMA software to calculate the assembly HPU, and assembly cost. If you were tasked with determining the yields on the Main Board Circuit Card Assembly, you could use an "as/like" product to predict the yields.

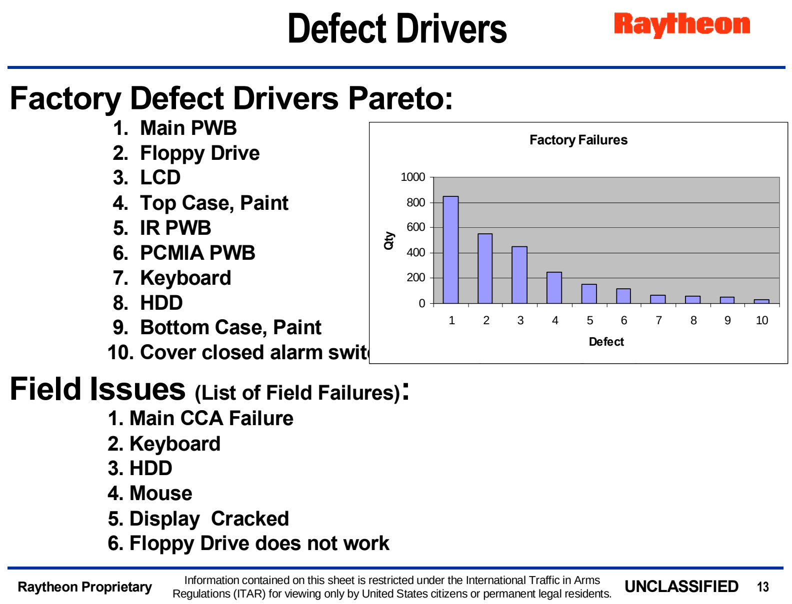
Step 4: <u>CHARACTERIZE</u>
What is the big picture system Cost for the proposed design, for design option #1, or design option #2?

What are the Top 10 Material Cost Drivers, for the proposed design, for design option #1, or design option #2? (Parts, Materials, Labor, Purchased Parts, Assembly, Test, etc.)

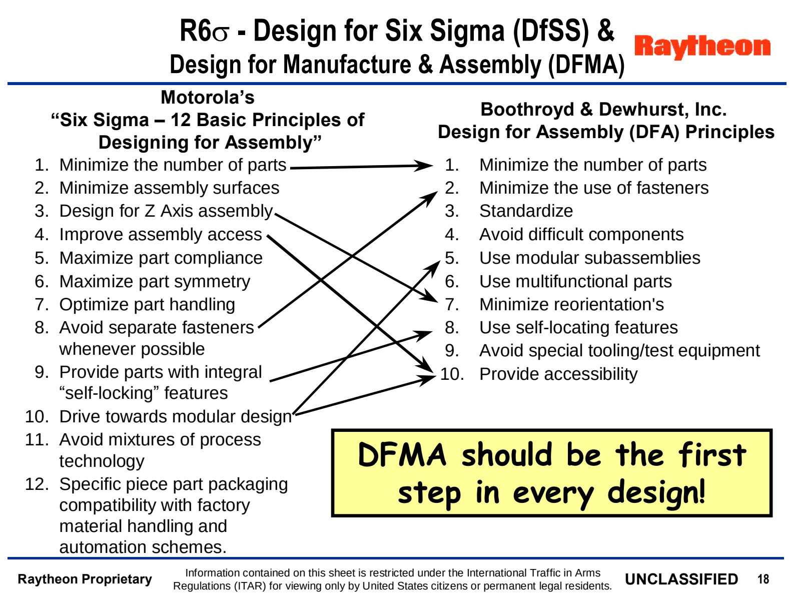
What are the system's Top 10 Defect Drivers, and their impact on cost, for the proposed design, for design option #1, or design option #2?

What are the Defects per Million Opportunities (DPMO) for the fabrication, and assembly, for the proposed design, for design option #1, or design option #2?

Once the Priorities have been established, the next step is to **CHARACTERIZE.** The team has to understand and characterize not only the performance impacts, system yields, first time build cost and hours per unit (HPU), sub-assembly cost and HPU, rework cost and HPU, and test cost and HPU, and the cost and HPU's rework the failures. They need to understand the impacts and develop various design approaches, to address the issues, and to maximize performance, and to improve system yields, and to minimize first time build cost and hours per unit (HPU), sub-assembly cost and HPU, rework cost and HPU, and test cost and HPU. Sometimes it is not feasible or possible to improve the process capabilities of a particular part or sub-assembly, and the IPT may need to focus on a risk mitigation plan to address the system yield problems.



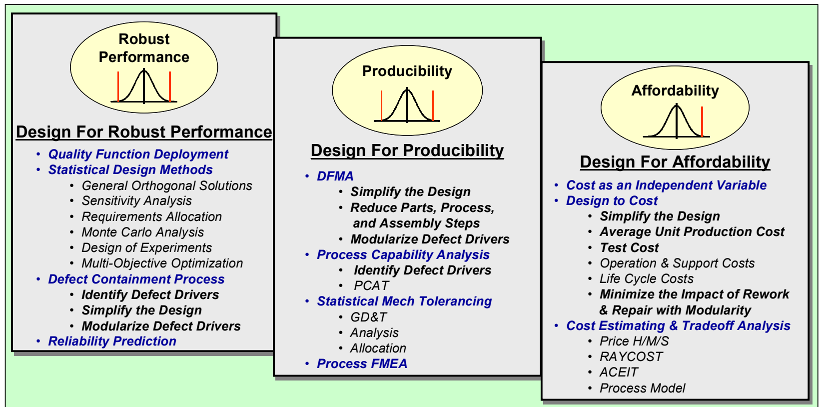
In order to develop the simplest design that meets the performance requirements, and cost goals, the IPT engineers should look at multiple design alternatives. The System and Sub-System design teams need to work together, and using the Design for Assembly Principles, and Motorola's Six Sigma – 12 Basic Principles of Designing for Assembly, develop the "Simplest Design that meets the Performance Requirements."



In attempting to eliminate parts, process and assembly steps the Engineer can start evaluating ways by which he/she can address the material cost issues. As design engineers we need to learn to reduce as many parts, processes, assembly steps, test steps, cycles of burn-in, the number of rework cycles, and the time required to re-work as we can to minimize the overall cost of the system. The fewer of everything, the lower the cost. End results would be:

- ✓ Fewer parts, less material cost
- ✓ Fewer parts, easier to assemble
- ✓ Fewer parts, fewer defects
- ✓ Fewer parts, less fabrication hours per unit
- ✓ Fewer assembly steps, reduced hours per unit
- ✓ Fewer assembly potting processes, reduced assembly hours per unit

- ✓ Fewer assembly potting processes, reduced assembly hours per unit
- ✓ Fewer alignments and special tooling, fewer alignment defects
- ✓ Fewer defect, less material cost
- ✓ Fewer defect, reduced sustaining cost



The Components of Design for Six Sigma (DFSS)

Once the design has been driven to the simplest design that works, then the team needs to focus on the system defect drivers. Relative to the defect drivers, the Classical 6σ Blackbelt, would say to eliminate the "Defect Drivers". However, the elimination of the Main Board Circuit Card Assembly, or the Display in a laptop computer is not a viable solution, and it would definitely detract from the systems performance. When addressing the defect drivers, the first step would be for the IPT to brainstorm ways to minimize the Cost impact of the known defect drivers. Sometimes it is not feasible or possible to improve the process capabilities of a particular part or sub-assembly, and the IPT may need to focus on a risk mitigation plan to address the system yield problems. Another option would be to modularize the Defect Drivers, making them sub-assemblies that are simple and easy to repair and replace. Let me stress the point, no matter what we do, the system's number one defect driver will probably always be in the "Top 10 Defect Drivers" list. If we focus on trying to minimize the cost impact of the defect drivers, and if we made it easy to repair and replace, not only would it reduce the cost in our assembly processes, but it will also make field repairs and maintenance easier. Also, if we develop a test procedure to validate the functionality, performance and quality of the sub-assembly modules, prior to the final system level assembly we would reduce the system repair cost driven by these defect drivers. Remember if there is a top-level system failure we must follow the following process in order to rework the unit.

Top Level Assembly Failures follow the following process:

✓ **First time build**	**Value Added**
✓ **First time unit test**	**Value Added**
✓ **First time burn-in**	**Value Added**
✓ **First time vibe**	**Value Added**
✓ **First time acceptance test**	**Value Added**
✓ **Rework tear down**	**Non-Value Added Waste**
✓ **Repair & replace Part or Parts**	**Non-Value Added Waste**
✓ **Reassemble the system**	**Non-Value Added Waste**
✓ **Retest - unit test**	**Non-Value Added Waste**
✓ **Retest - burn-in**	**Non-Value Added Waste**
✓ **Retest - vibe**	**Non-Value Added Waste**
✓ **Retest - acceptance test**	**Non-Value Added Waste**

FAILURES COST MONEY driving up sustaining hours, material costs, and results in added repair costs, and retest costs. This is where Design for Six Sigma (DFSS) and DFMA come into product development and into the process of improving the product designs. Through the use of DFSS and DFMA engineers can reduced the number of parts and simplify the overall system design.

Once the IPT has developed some conceptual design alternatives, that meet all of the performance requirements, then the team needs to Characterize each design approach. When characterizing the design approaches, the team should be looking at:

- ✓ Performance Characteristics
- ✓ Material Cost
- ✓ Rework Cost
- ✓ Yields
- ✓ Hours per Unit – first time build, rework, test

The engineer then needs to allocate system performance requirements, statistical allocate tolerances across the system and sub-assemblies, and complete tolerance analysis on the system and sub assemblies to assure the design is interchangeable, meets the functional design requirements, and using Process Capabilities assure that Sub-Assemblies, and parts are manufacturable.

Step 5: <u>IMPROVE</u>
Select the best design approach to reduce the big picture system Cost.

Select the design approach that minimizes the impact of the system's Top 10 Defect Drivers.

Select the design approach that minimizes the cost of the Parts, Sub-Assemblies, and at the System Level.

The next step is **<u>IMPROVE</u>**. Now that the team has characterized several different design approaches this step is relatively simple. This is where the rubber meets the road, and the IPT needs to make a decision. All the team needs to do is select the design approach that meets the objective of the business, the program, and the performance requirements for the system. Out of the options addressed by the IPT they need to determine which Option offers the best solution relative to Cost, Performance, and Quality. The intention is to let all of the data that has been pulled together guide the decision of the design team.

Step 6: <u>ACHIEVE</u>

Last but not least is **<u>ACHIEVE</u>**. The team, having committed to the development of a product, that meets the Customer needs, system performance requirements, and business objectives, will have evaluated several different design approaches in order to assure their vision can successfully be achieved. With their design approach being focused not only on performance, but also on what the Customer truly wants, and meeting business objective, the team can't help but achieve! Both a delighted Customer, because we meet his performance goals, schedule (the design and manufacturing schedule) and cost goals, and Raytheon will be more profitable because we can both manufacture and assemble the system without attaching cash to each and every system that goes out the door.

SUMMARY:
When designing a system follow the Six Step Process:
Step 1: <u>VISUALIZE</u>
1) Visualize – Develop a Common Vision:
   a) What does the Customer Want?
   b) What does the Company Want?
   c) As an Engineer, what do I want?
2) Develop system level goals
   a) Performance
   b) Cost
   c) Schedule

Step 2: <u>COMMIT</u>
1) Work with the Customer, Program Management and Integrated Product Development Team to develop a Common Vision and Commitment.

Step 3: <u>PRIORITIZE</u>
1) Develop a method to focus and/or prioritize your work.
2) Evaluate the system at the system level to better understand:

a) System performance
b) System yields
c) First time build cost, and hours per unit (HPU)
d) Sub-assembly cost and HPU
e) Test cost and HPU
f) Rework cost and HPU's

3) Once the team understands the system level performance, yields, HPU and costs, then the IPT should focus on what they need to work on.

Step 4: <u>CHARACTERIZE</u>

1) Characterize
   a) System performance
   b) System yields
   c) First time build cost, and hours per unit (HPU)
   d) Sub-assembly cost and HPU
   e) Rework cost and HPU
   f) Test cost and HPU
   g) Rework cost and HPU's

2) Develop various design approaches, to address the issues, to maximize performance, to improve system yields, and to minimize first time build cost and hours per unit (HPU), sub-assembly cost and HPU, rework cost and HPU, and test cost and HPU.

Step 5: <u>IMPROVE</u>

The IPT needs to make a decision, and select the design approach that meets the objective of the business, the program, and the performance requirements for the system. Out of the options addressed by the IPT they need to determine which Option offers the best solution relative to Cost, Performance, and Quality.

Step 6: <u>ACHIEVE</u>

In my opinion Achieve is the step we do the worst. The team should be recognized for having done a good job, and for developing a system the delights the Customer. A system that delights the customer is a system that meets performance goals, schedule (the design and manufacturing schedule) and cost goals.

If you read this far, I need to celebrate my achievement, and thank you for having read the paper. I hope my effort was worth it, and I hope you enjoyed reading it. I hope you learned something as well. Thanks again, Paul!